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An Overview of NASA's In-Space Cryogenic Propellant Management Technologies

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Stephen Tucker and Leon Hastings
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An Overview of NASA Efforts on In-Space Cryogenic Propellant Management Technologies

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Future mission planning within NASA continues to include cryogenic propellants for in-space transportation, with mission durations ranging from days to years. Between 1995 and the present, NASA has pursued a diversified program of ground-based testing to prepare the various technologies associated with in-space cryogenic fluid management (CFM) for implementation. CFM technology areas being addressed include passive insulation, zero gravity pressure control, zero gravity mass gauging, capillary liquid acquisition devices, and zero boiloff storage. NASA CFM technologies are planned, coordinated, and implemented through the Cryogenic Technology Working Group which is comprised of representatives from the various NASA Centers as well as the National Institute of Standards and Technologies (NIST) and, on selected occasions, the Air Force. An overview of the NASA program and MSFC roles, accomplishments, and near-term activities are presented herein. Basic CFM technology areas being addressed include passive insulation, zero gravity pressure control, zero gravity mass gauging, capillary liquid acquisition devices, and zero boiloff storage. Recent MSFC accomplishments include: the large scale demonstration of a high performance variable density multilayer insulation (MLI) that reduced the boiloff by about half that of standard MLI; utilization of a foam substrate under MLI to eliminate the need for a helium purge bag system; demonstrations of both spray-bar and axial-jet mixer concepts for zero gravity pressure control; and sub-scale testing that verified an optical sensor concept for measuring liquid hydrogen mass in zero gravity. In response to missions requiring cryogenic propellant storage durations on the order of years, a cooperative effort by NASA's Ames Research Center (ARC), Glenn Research Center (GRC), and Marshall Space Flight Center (MSFC) has been implemented to develop and demonstrate "zero boiloff (ZBO) concepts for in-space storage of cryogenic propellants. An MSFC contribution to this cooperative effort is a large-scale demonstration of the integrated operation of passive insulation, destratification/pressure control, and cryocooler (commercial unit) subsystems to achieve zero boiloff storage of liquid hydrogen. Testing is expected during the Summer of 2001.

Cryogenic Fluid Management Presentation Agenda

- Goals and Technology Working Group
- Recent Accomplishments and Ongoing Activities
  - Passive insulation (short-term storage ~mo)
  - Zero-g pressure control
  - Mass gauging
  - Capillary liquid acquisition
  - Propellant transfer
  - Long-term storage (~yrs)
    - Active heat removal—zero-boiloff concept
    - Early demonstrations
- Future Activities

Cryogenic Fluid Management Technology

- Cryogenic Technology Working Group Formed in Fall 1997
  - Established to coordinate agency technology planning, accomplishments, and mission applications.
  - Promote coordination with Air Force, other government agencies, and industry
  - Chairman: David Plachta, NASA GRC
  - Deputy Chairs: Leon Hastings, MSFC; Peter Kittel, ARC; and Lou Salerno, ARC.
  - Active members:
    - Robert Johnson, KSC
    - Eric Marcquardt, NIST
    - Bob Miyake, JPL
    - Todd Peters, JSC
    - Simon Chen, GRC
    - Joe Gaby, GRC
    - Stephen Tucker, MSFC

CFM Technology Goals

- Zero-G Pressure Control Without Propellant Resettling
- Propellant Acquisition Without Propellant Resettling, ie, Capillary Liquid Acquisition Devices (LAD's)
- Propellant Transfer Without Excessive Losses
  - On-orbit
  - Upper stage fill during launch vehicle ascent
- Measurement of Liquid Mass Without Resettling
- Cryogenic Storage
  - Passive insulation (~months)
  - Active heat removal—zero boiloff (~years)
    - Advance cryocooler technologies for liquid hydrogen (LH_2) and liquid oxygen (LO_2)
    - Integrate with passive insulation storage

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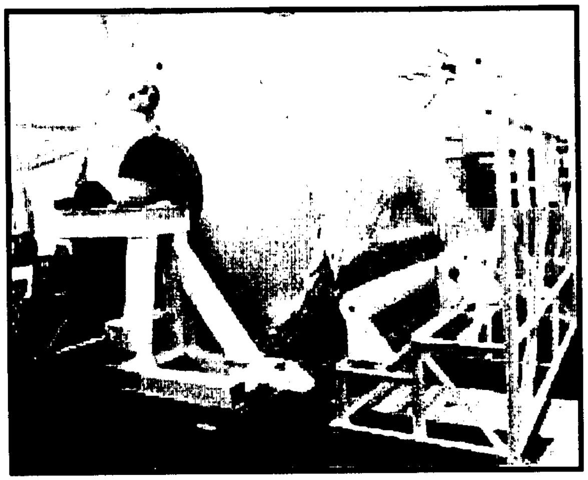
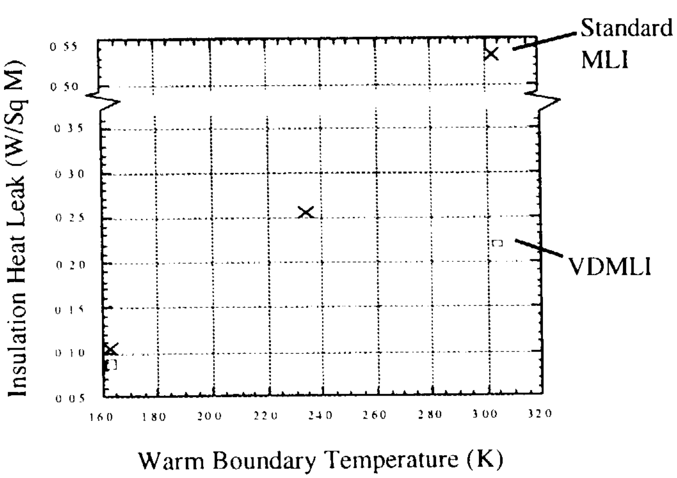
High-Performance Cryogenic Insulation



Roll Wrap Installation of Variable Density MLI



- Description:
  - Perform large-scale demo of LH_2 insulation concept on 639 ft^3 multipurpose hydrogen test-bed (MHTB) tank in simulated mission environments
  - Evaluate foam/innovative multilayer insulation (MLI) concept for ground-launched upper stages
  - Demonstrate 45-day LH_2 orbit-hold capability
  - Demonstrate less costly MLI installation techniques
  - Funded by OAST/Code R: ASTP
- Status, Results, and Plans:
  - Foam eliminated MLI He purge bag normally required for ground-hold and ascent flight protection
  - Variable density MLI: Reduced heat leak 46 %, weight 41 % compared to best previous MLI
  - Roll-wrap MLI installation saved 1,200 manhours.
  - MSFC testing completed June 1996.
  - Papers: STAIF 1–98, AIAA–2000–3790, and CEC–C–10B–01
  - Report: NASA/TM–2001–211089, June 2001

POC: Leon Hastings at 1–256–544–5434

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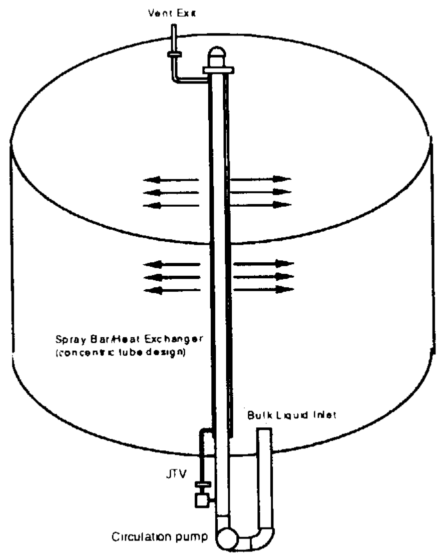
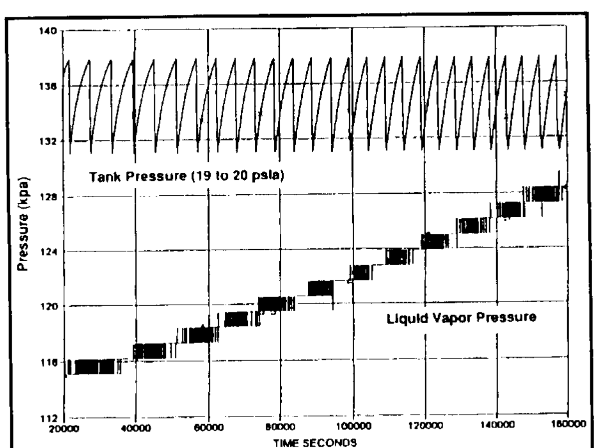
Zero–G Pressure Control—MHTB Testing





- Description:
  - Demonstrate concepts for zero-g pressure control using large-scale (639-ft^3) LH_2 tank.
  - Evaluate long-term pressure control for 3-day simulated orbital coast period utilizing both spraybar and axial-jet mixer/heat exchanger concepts.
  - Funded by Code R.
- Status, Results, and Plans:
  - Spraybar zero–g pressure control subsystem was installed June 1996, LeRC axial jet subsystem in late 1997.
  - Spraybar successfully maintained pressures between 19–20 psia at multiple fill levels. Demonstrated capability to subcool LH_2 to 10 psia.
  - Axial-jet testing was compromised by low mixer output due to electronic problems—pressure controlled at 90 % fill.
  - Tests completed in November 1996 and April 1998.
  - Papers: AIAA–99–2175, Thermal and Fluids Analysis Workshop 9–99, and NASA TM fall 2001

POC: Robin Flachbart at 1–256–544–6052

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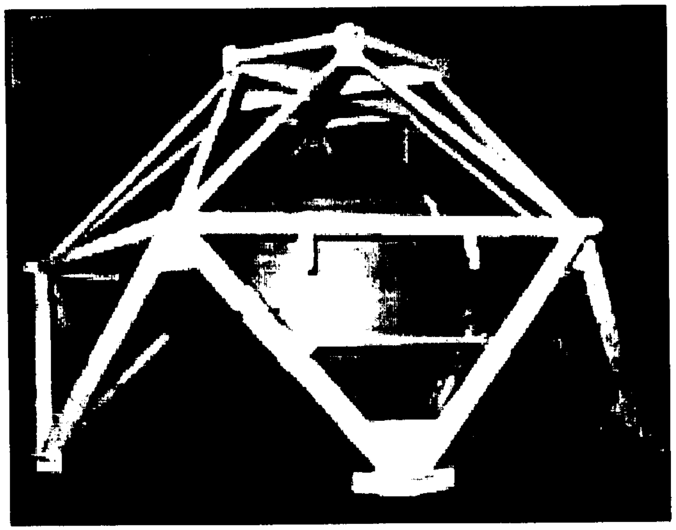
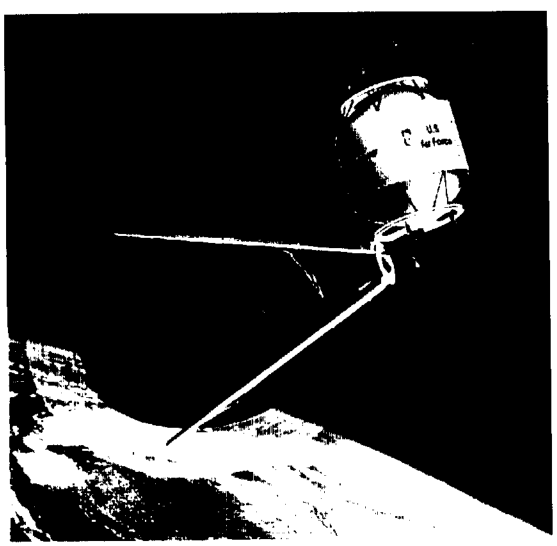
Zero G Pressure Control Solar OTV's





Solar OTV Concept

- Description:
  - AITP with Boeing: Use Thermodynamic Vent System (TVS) in dual role: (1) Control tank pressure and (2) feed solar engine, i.e., no boiloff losses.
  - Cooperative Agreement with SRS Technologies: Eliminate TVS. Numerous burns/propellant resettling sequences enable selective extraction of either liquid or vapor to control tank pressure.
- Results and Status:
  - Boeing tests completed in April 1999.
    - Successful 30-day mission simulation of 140 burns with 0.65-to 2.4-hr durations
    - Paper: AIAA–99–2604
    - Report: MDC 99H0078
  - SRS tests completed 6–00
    - Ten-day test validated concept feasibility
    - Data evaluation in progress
  - Application of data cross-cutting

POC: R. Flachbart or L. Hastings (MSFC)

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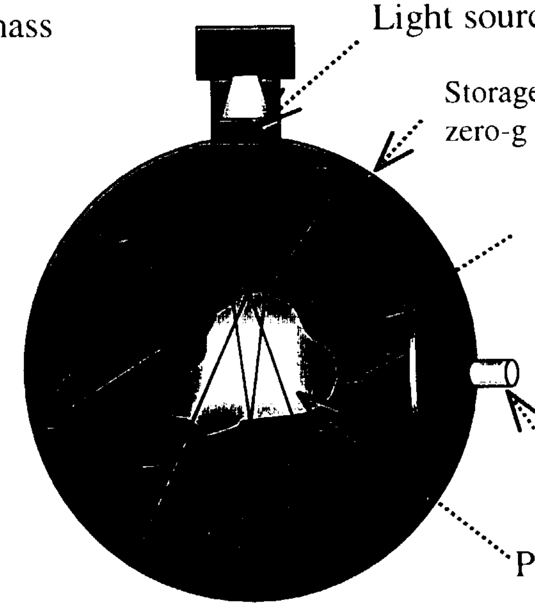
Optical Mass Gauge Background and MHTB Testing

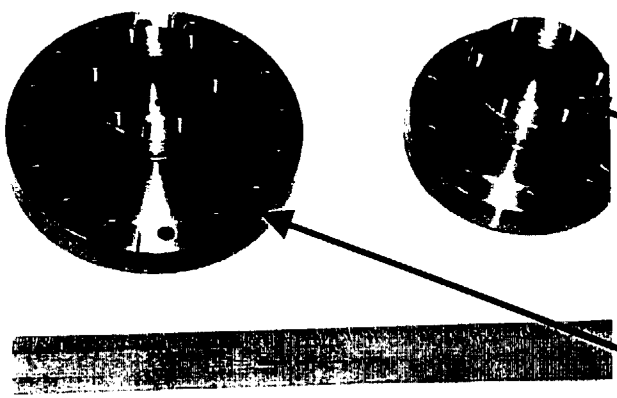
- Background
  - Developed by JUSTAK, Inc through SBIR Program
    - Emitter-diode laser provides light source
    - Detector measures light energy received
    - Intensity of energy detected proportional to liquid mass in tank
  - Bench tested with LH_2 summer and Fall 2001
    - Tested at MSFC by IITRI, Bldg. 4628
    - Fifteen-gal dewar
    - Confirmed LH_2 absorption coefficient
    - Enhanced sensor location and baffle selections
    - Concept validation
- MHTB Testing
  - Provide first large-scale LH_2 data
  - Confirm sensor geometry independent of tank size
  - Define measurement accuracy
    - Constrained by accuracy of MHTB level sensors
    - Will ascertain repeatability
  - Testing in progress: Initial results indicate good accuracy

MSFC POC: Chad Bryant 1–256–544–5678

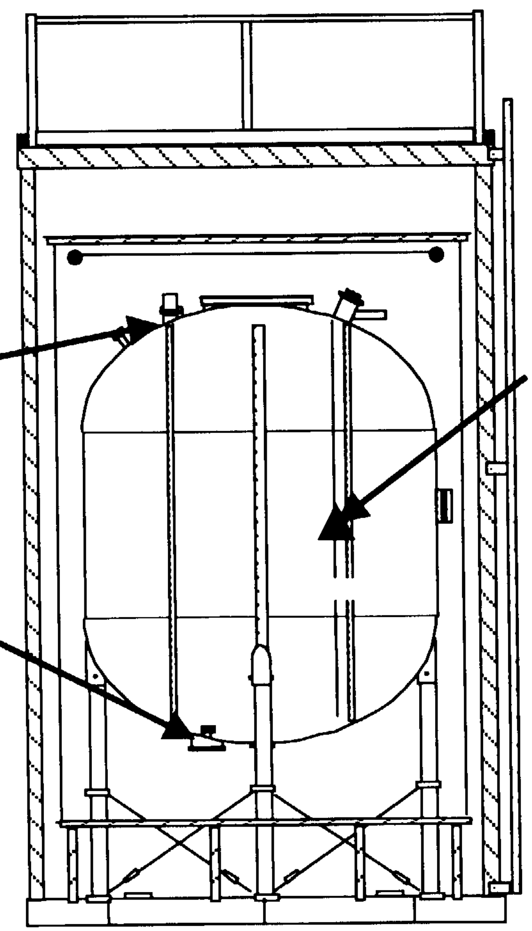


Optical Mass Gauge and Level Sensor/MHTB Integration

Mass Gauge



Sierra Lobo Sensor



- Array of silicon-diode temperature sensors serve as liquid level indicators

Level sensor at 50 % level on existing instrument tree

MHTB 639 ft^3 Tank

Note:
Flanges have quartz viewing Ports
with gaseous helium (Ghe) purge capability

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Capillary Liquid Acquisition Device Activities

LH_2 Screen Channel LAD

- Description:
  - No orbital experience with cryogenic capillary liquid acquistion devices (LAD's)
  - Existing ground-test data base meager
    - Conflicting LH_2 data regarding pressurant effects
    - LO_2 data almost nonexistent
  - Phenomena of interest:
    - Localized heating/entrapment
    - Bulk propellant saturation conditions
    - Wicking, evaporation, and condensation
  - Funding by OAST/Code R
- Status, Results, and Plans:
  - GRC bench testing with LN_2 and LH_2—tests completed
  - MSFC bench testing:
    - Manufacturing variability effects completed Dec. 1998
    - LN_2 heat entrapment survey tests summer 2001

POC: Leon Hastings 1–256–544–5434 and Jason Turpin 1–256–544–2807

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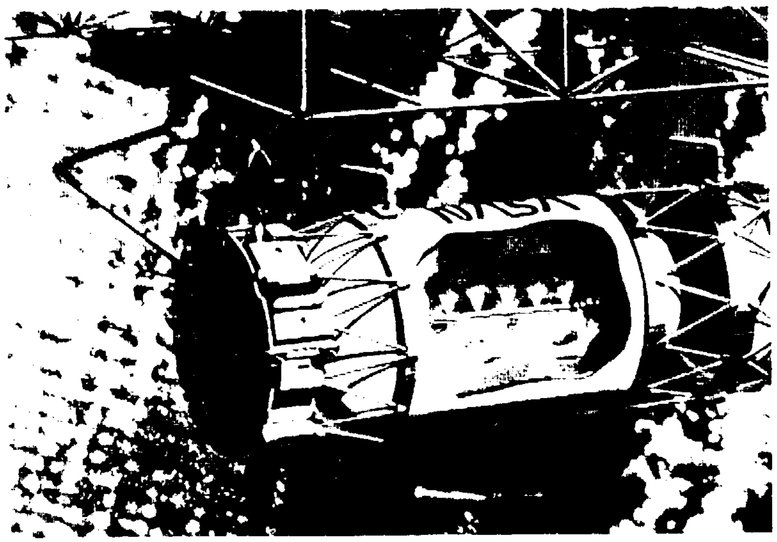
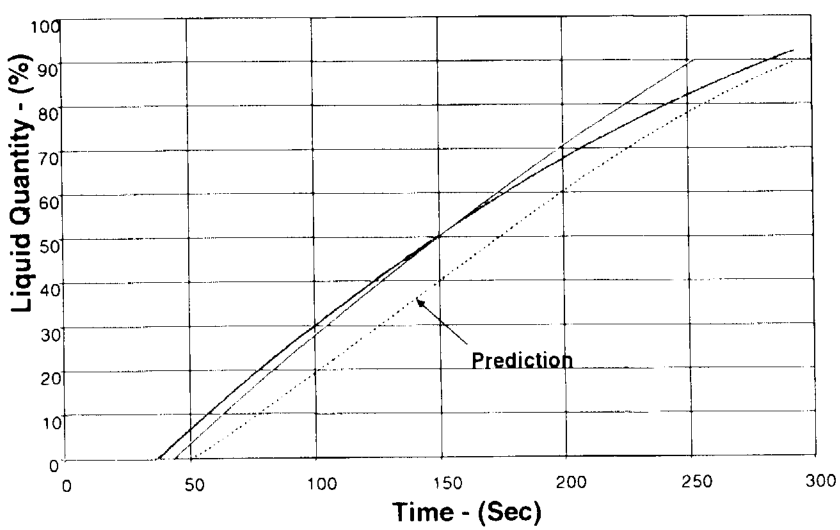
Rapid Chill/Fill Test





- Description:
  - Demonstrate LH_2 tank rapid chill/fill with a spraybar injector.
    - 50 ft^3 at GRC, 639 ft^3 at MSFC
  - Provide data to anchor thermal-fluid analytical model.
  - Supports in-space cryogenic fluid transfer and Boeing's Advanced Shuttle Upper Stage (ASUS).
- Status, Results, and Plans:
  - Small scale testing (50-ft^3 tank) completed at GRC in 1998
  - MHTB testing (639 ft^3) completed fall 2000
    - Demonstrated 5-minute fill capability
    - Film boiling can slow chilldown process.
  - Paper: CEC July 18–20, 2001

POC: Robin Flachbart 1–256–544-6052

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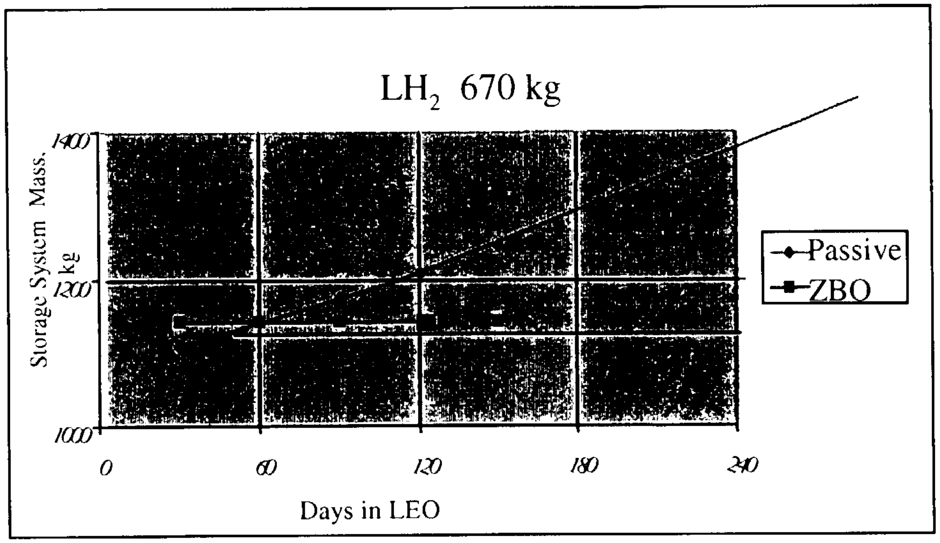
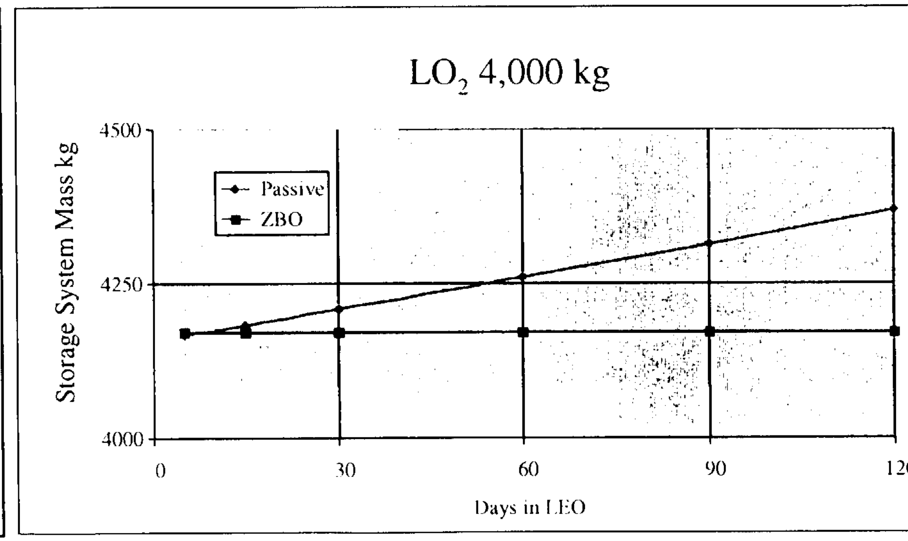
LH_2 and LO_2 Storage System Mass Versus Time in Low Earth Orbit (LEO) Passive and Active (Zero-Boiloff) Concepts





POC's: Stephen Tucker 1–256–544–0500 or L. Hastings 1–256–544–5434

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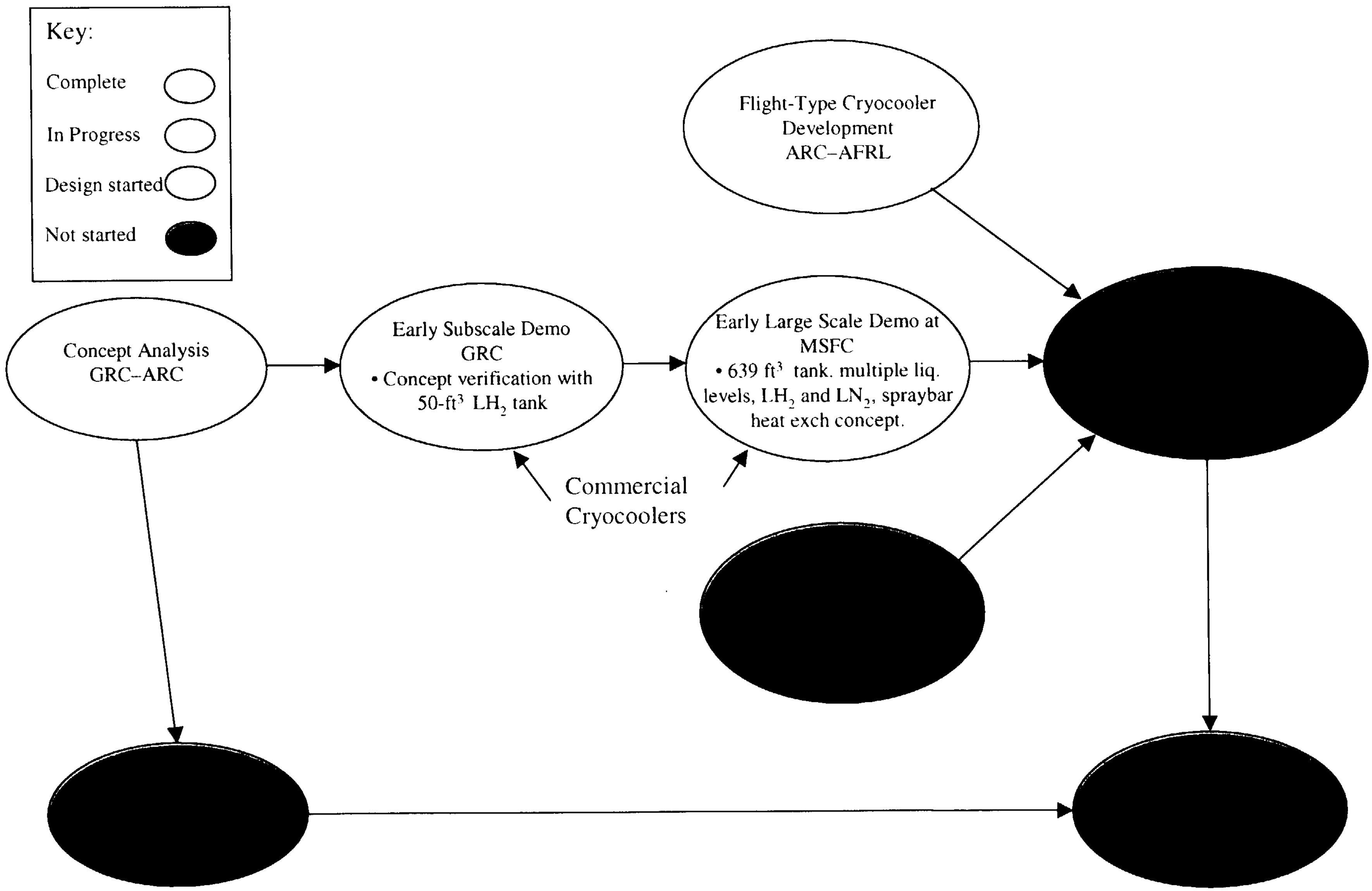
Zero-Boiloff Cooperative Technology Effort GRC, MSFC, ARC, and Air Force



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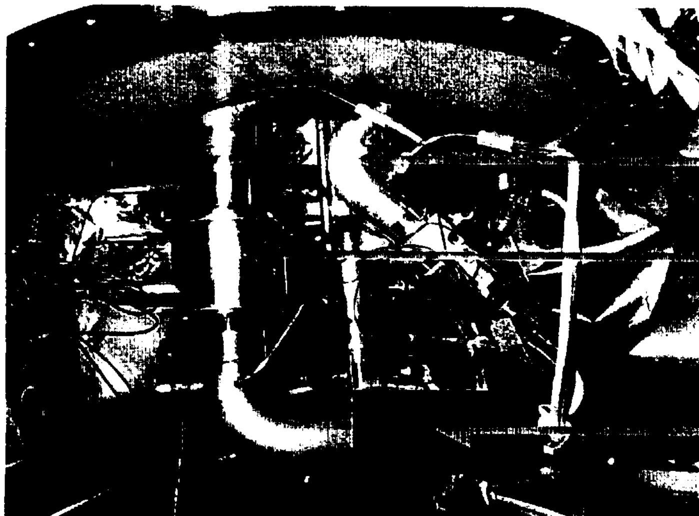
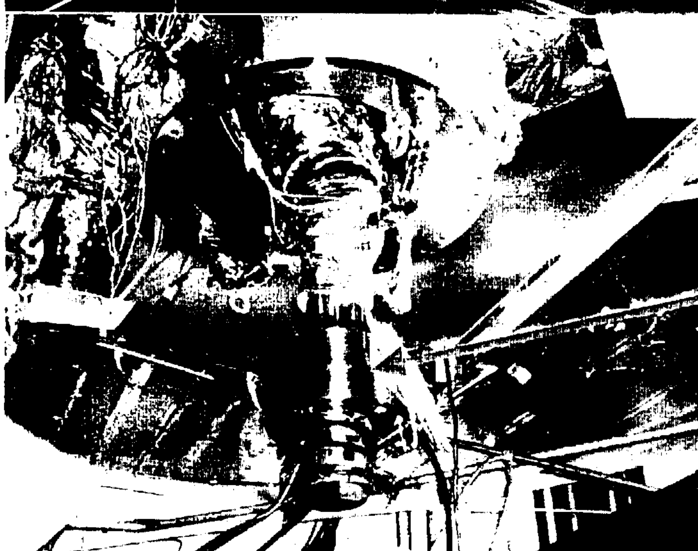
Early Zero-Boiloff Demonstration with MSFC's MHTB

Cryocooler Installation





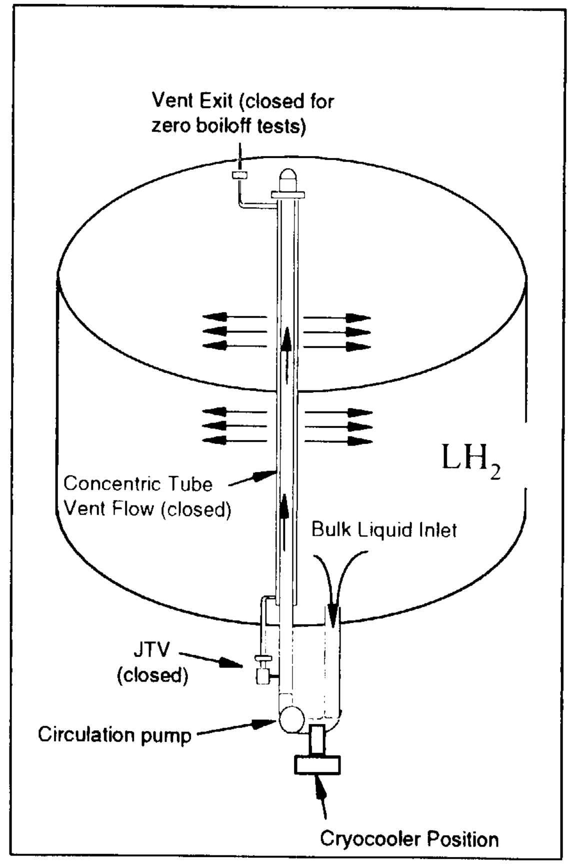
Recirc Line

Recirc Pump

Cooling Head
Hx Position

Cooler
Installed

Test Setup Schematic



- ¥ 639-ft3 LH_2 Tank
- ¥ Commercial Cryocooler
- ¥ Multiple fill levels
- ¥ Pumped Loop Spraybar Mixer

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CFM Technology—Future Activities

- Emphasize Zero-Boiloff Technology
  - Develop flight-type cryocoolers
    - LH_2 and LO_2
    - For large storage capability
  - Upgrade system level demonstrations as cryocooler technologies progress
- Continue Development of Companion Technologies
  - Pressure control
  - Liquid acquisition
  - Mass gauging
  - Propellant transfer
- Advocate Flight Experiments